Chapter 11

AgMIP Regional Activities in a Global Framework: The Brazil Experience

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Introduction

Climate variability and change are projected to increase the frequency of extreme high-temperature events, floods, and droughts, which can lead to subsequent changes in soil moisture in many locations (Alexandrov and Hoogenboom, 2000). In Brazil, observations reveal a tendency for increasing frequency of extreme rainfall events particularly in south Brazil (Alexander *et al.*, 2006; Carvalho *et al.*, 2014; Groissman *et al.*, 2005), as well as projections for increasing extremes in both maximum and minimum temperatures and high spatial variability for rainfall under the IPCC SRES A2 and B2 scenarios (Marengo *et al.*, 2009).

Agribusiness is responsible for about 30% of the Brazilian economy and is a critical contributing sector for economic growth and foreign exchange. Agriculture accounted for about 23% of GDP and 27% of Brazilian exports in 2013. In 2013 Brazil showed a positive agricultural trade balance of US $ 99.97 billion USD (MAPA, 2014) Brazil is the world's largest producer of sugarcane, coffee, tropical fruits, and frozen concentrated orange juice. It has the world's largest commercial cattle herd (50% larger than that of the USA) at 210 million head. Brazil is also an important producer of soybeans (second only to the United States), as well as maize, cotton, cocoa, tobacco, and forest products. The remainder of agricultural output is

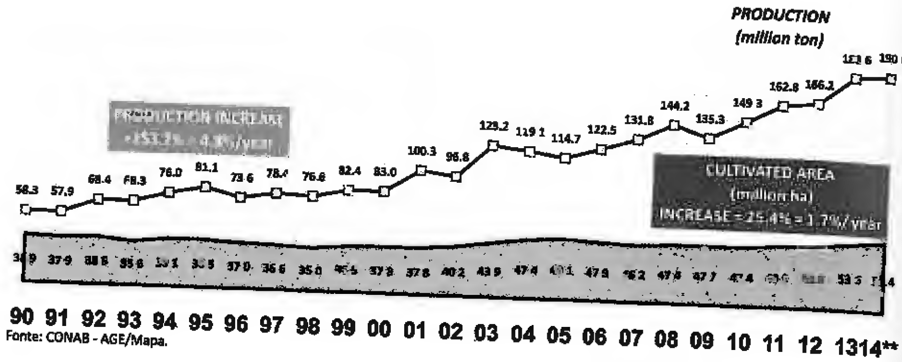

Fig. 1. Grain production and area increase in Brazil from 1991–2013.
Source: http://www.conab.gov.br/conteudos.php?a=1252&t=2. ** 2014 (estimated).

in the livestock sector, mainly the production of beef and poultry, pork, milk, and fish.

Between 1996 and 2013, the total value of Brazil's crops rose from US $12 billion to US $330 billion. Brazil increased its beef exports tenfold in a decade, overtaking Australia as the world's largest exporter. It is also the world's largest exporter of poultry, sugarcane, and ethanol. Since 1990, national soybean production has risen from less than 15 million tons per year to over 60 million tons. Brazil accounts for about a third of world soybean exports. In 1994, Brazil's soybean exports were one seventh of the USA's; now they are six sevenths. Moreover, Brazil supplies a quarter of the world's soybean trade on just 6% of the country's arable land. From 1991 to 2010, the grain production of the country (cotton, peanut, rice, bean, sunflower, corn, soybean, sorghum, wheat, oat, barley, castor bean, rye, and rapeseed) increased by 147%, while cultivated area increased only 25%; or 4.8%/year and 1.7%/year respectively (Fig. 1). This was due to major development in agricultural technology.

These statistics highlight the importance of agriculture for the country's economy, as well as the challenges faced by Brazil related to projected climate change impacts on the agricultural sector. During the last decade, intense interest has been focused on what and how research strategies could help Brazilian agriculture to cope with climate change. The philosophy and protocols of the Agricultural Model Intercomparison and Improvement Project (AgMIP) (Rosenzweig *et al.*, 2013), have converged with these discussions. Since 2009, Brazil has implemented a national climate change policy, with emphasis on energy, agriculture, industry, and especially on the great effort to reduce deforestation in the Amazon region. In terms of mitigation of greenhouse gases, a set of the national actions was defined. In the agriculture sector, a policy of low carbon emissions was adapted, whereby emissions should be reduced by 30% by the year 2020 through the adoption of appropriate agricultural

practices. The next principal challenge is the identification of possible adaptations to high temperature, reduction of rainfall, and increased CO_2

In order to relate the Brazil experience under the AgMIP framework (Rosenzweig *et al.*, 2013), we analyzed the impacts of climate change on agriculture and the environment based on two main aspects. The first one involves the agricultural sector as a whole, as it is expected that Brazil will play a significant role in global food security in the coming decades. Indeed, the OECD/FAO joint report "Agricultural Outlook 2012" (OECD/FAO, 2012) estimates that agricultural production needs to increase by 60% over the next 40 years to meet rising demand for food. Additional production will be necessary to provide raw material for bio-fuel and non-food agricultural products, including cotton, timber wood, and cellulose paste. Most of this additional supply is expected to come from developing countries and emerging economies, with a sizeable share from Brazil. In fact, Brazil still has a large stock of agricultural land available to be brought into sustainable cultivation by entrepreneurial local farmers, and in the last three decades local research-and-development institutions have mastered technology for tropical agriculture. However, this positive outlook should be balanced by several factors, including deficits in infrastructure, institutional risks, and, in particular, the uncertainties associated with climate change.

Brazilian agriculture is moving from subtropical regions of the south to the tropical areas of the Brazilian Savannahs in the midwest and northwest, where production is mainly rainfed. In spite of technological progress, which is responsible for nearly 75% of increased output in the last 20 years (Gasques *et al.*, 2012), the total factor of productivity is still largely dependent on the rainfall regime, notably the quantity, distribution, and frequency of rains and dry spells throughout the seasons (Carvalho *et al.*, 2013). Rainfall regimes are rapidly changing and will be further affected by climate change in the near future. This could have an impact on both local welfare and world food production. In considering the impacts on local welfare, one should note that farming in Brazil is neither an enclave activity (as it had been in the past) nor itinerant (as depicted by the misleading image of tropical farming as a slash-and-burn practice that leaves only ashes behind after a few years of high yields provided by unsustainable exploitation of natural resources).

The agriculture established in the frontier regions of the midwest, north, and northwest has occupied undeveloped land, created many cities where millions of Brazilians now live, and engaged many in activities that are mostly associated with agricultural production and agribusiness. Some questions should be raised to guide planning in this regard: What is the expected impact of climate change on Brazilian agriculture, particularly on tropical agriculture that is currently responsible for the booming Brazilian agribusiness? What are the possible consequences regarding the ability to feed the world and, in particular, the Brazilian population? This is

a dimension we explore by using data from EMBRAPA (Brazilian Agricultural Research Corporation), which has good indicators and rigorous studies by which we can do a critical review.

The second aspect for which we analyzed the impacts of climate change on agriculture and the environment relates to the desertification of Brazil's northeast semi-arid region, which has the highest population density of any semi-arid region in the world (Assad *et al.*, 2013). The northeast, and its semi-arid region in particular, is the poorest part of the country, with the largest poor population in Latin America. The Brazilian semi-arid region is characterized by large social inequalities and massive poverty. According to Assad *et al.* (2012); 58% of the Brazilian poor live in the semi-arid region and more than 70% of the semi-arid region population lives in poverty or extreme poverty conditions. Among 1,133 municipalities, many have a low human development index (HDI) and only reach national average values of HDI. The process of desertification is also underway, and could accelerate with climate change (Assad *et al.*, 2013). In 2012, the region had experienced the third successive year of drought, with severe social impacts. The problem of desertification in the northeast is not new, but it is getting worse. This issue is explored in this chapter, through observed data and climate change projections with a critical review of the debate and with presentation of strategies and policies for responding to ongoing desertification and climate change.

Brazilian Agricultural Climatic Risk Zones and Climate Change Impacts

A coordinated effort that helps to organize agroclimatic activities in Brazil is the Brazilian Agricultural Climatic Risk Zones Project, which was started by the Ministry of Agriculture of Brazil in the early 1990s and still guides agricultural development in the country. The initiative is based on the understanding that the agroclimatic potential of such regions may be established based on parameters that define temperature and soil water regimes appropriate for specific crops.

Deciding what, when, and where a crop should be sown, for a certain risk level, is a direct function of weather in the plant cycle. The process of creating agricultural climatic risk zones integrates simulation models of crop growth based on data from climate, soil, and phenological characteristics of the crop, as well as techniques of geographic information systems (GIS) and decision analysis.

In Brazil, the official risk zones have been public policy since 1996. For each of the 5,564 municipalities of the country, crop suitability is defined for planting with less than 20% risk of economic success in the harvest. These statements are made based on the phenology of each cropping system, by considering the negative effects of excess water, drought, or extreme temperatures in the critical phases of the plant. Lack of water during grain-filling can damage a crop of maize or soybeans.

Excessive rain at harvest time can impair the quality of the grains. The incidence of extreme temperatures can cause loss of production due to flower abortion in the case of high temperatures or frost damage by low temperatures.

In 2001, EMBRAPA and UNICAMP (State University of Campinas) developed a system to simulate the different conditions of climate and soil for application to risk zonation of agricultural crops. The results obtained created a basis for a near-complete knowledge of the agricultural geography of Brazil.

The zonation of climatic hazards developed by EMBRAPA and UNICAMP, in collaboration with other research institutions in Brazil, assesses the suitability of a particular region to a particular type of crop, not only with weather data (rainfall and temperature), but also with specific indices developed to characterize the sensitivity of the crops to extreme events that may occur during critical phenological stages. The use of GIS and satellite images is essential in this process. With this information, it is possible to show the likelihood of obtaining yields with at least minimal economic productivity. Moreover, the evolution of climate modeling, with resulting projections of future climate scenarios due to global climate change, enables projections of the redistribution of crops according to the rising temperatures. In this case, the methodology is similar to the risk zonation, with the difference that it also takes into account other factors such as increased evapotranspiration and moisture deficit or surplus due to high temperature (Fig. 2).

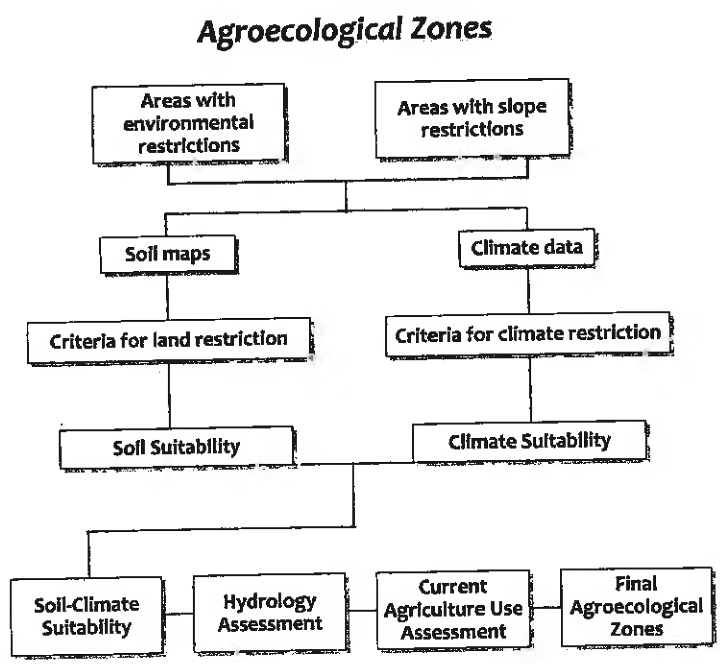

Fig. 2. Flowchart of agroecological zones methodology.

This methodology was adapted from the agroecological zones methodology developed by Food and Agriculture Organization. It has been used for studies of bioenergy products and rice in Brazil (Monteiro *et al.*, 2013). The data are processed to calculate potential evapotranspiration (PET) and crop water requirements (ISNA, indice de satisfação de necessidade de água), which are defined as:

- Potential evapotranspiration (PET), according to Thornthwaite and Mather (adapted after correction by Penman evapotranspiration methods), is an estimate of water evaporation from the soil and transpiration by plants at full capacity, with the soil completely covered by grass and there is an optimal supply of water in the root zone. In this study, the PET is calculated as a function of temperature, according to the method of Camargo and Camargo (1983).
- ISNA can be considered as the rainfall requirement of the crop and is expressed in terms of millimeters and is similar to crop water-stress index.

To assess the availability of soil water during the critical phases of crop growth, we used the concept of ISNA, represented by the relationship between actual evapotranspiration and the potential evapotranspiration (RET/MET; real evapotranspiration divided by maximum evapotranspiration). The values normally used are around 0.60 (Zullo *et al.*, 2006). This concept allows the estimation of probabilities of occurrence of phenomena that affect crop water productivity.

The principle for determining the type of climate risk is simple. The areas of lowest risk are those where there is sufficient water to guarantee germination and, especially, flowering and grain-filling, which comprise the important phenological stages affecting the productivity of crops. This risk is set not to exceed 20%. In the case of global climate change, the increase of MET reduces ISNA, which thereby increases climate risk. In the case of agricultural zonation of climatic hazards, the method was adopted for most grain crops, as they are short-cycle annuals.

To define the risk, agrometeorological indices are calculated from crop evapotranspiration, which is the sum of leaf transpiration and soil evaporation. It can also be defined as the total amount of water lost from a surface covered with vegetation through direct evaporation of water from crop interception and the soil surface. Each crop has its optimum water requirement, regulated for photosynthesis, which depends directly on the amount of water available and air temperature. When these conditions are met, planting is recommended. By these criteria, one can delineate the area in which any crop can be produced in Brazil and the associated risks. After mapping the potential crop areas, we then introduce climate change scenarios for future years, i.e., 2020s, 2030s, and 2040s (Assad *et al.*, 2013). Figure 3 shows the flowchart for calculating the climatic risk for grains.

Finally, when the climatic suitability zonation is calculated, the thermal limits are considered as well as the stressing incurred by crops. In this particular case,

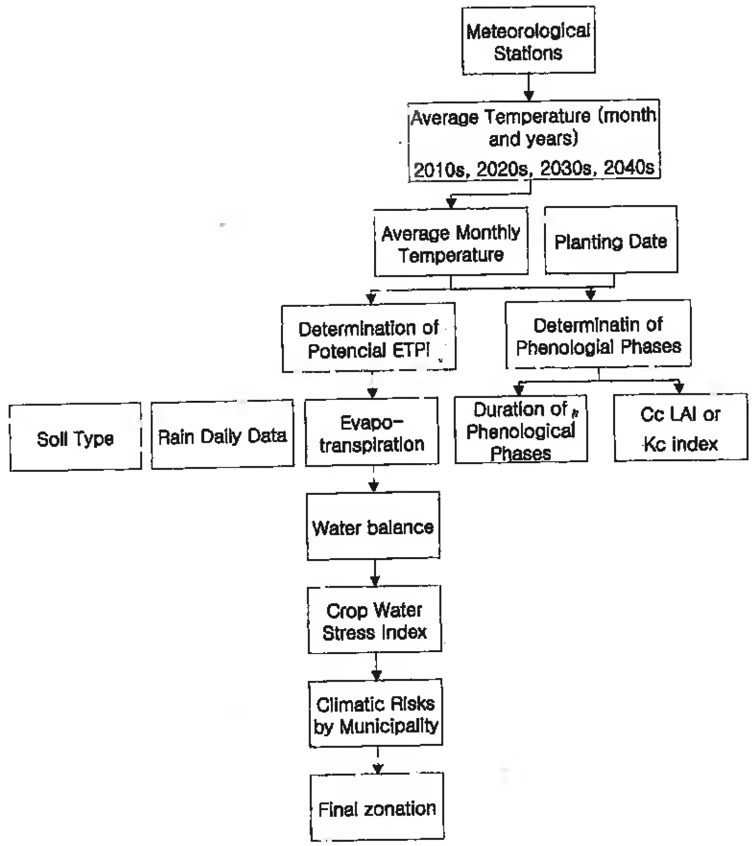

Fig. 3. Flowchart of the agricultural zonation of climatic risks for grains (Zullo Jr *et al.*, 2008).

the risk of frost or of high temperature is considered. It is important to note that this concept of fitness allows the simulation of an important agroclimate index that can be represented by altimetry as an easy way to map temperature. Regression equations developed for each region allow the estimation of maximum and minimum temperature as a function of latitude, longitude, and altitude. The altimetry data are obtained from USGS (United States Geological Survey), with contour lines established every 900 m horizontal distance, or 30 x 30 m in some cases.

Data and climate models

The annual water deficit is obtained from the simulation of the climatic water balance, where the monthly average temperature data are estimated from regional regression equations of temperature. The values of average monthly precipitation are calculated from the time-series of rainfall data available in the Agritempo system (www.agritempo.gov.br).

The availability of climate models, either global or regional, enabled the development of future scenarios, with lower or higher resolution for climatic variables including temperature, rainfall, and solar radiation.

In 2001, EMBRAPA and UNICAMP developed a method using global climate models with simulation of temperature increase according to global projection from IPCC (2001). This temperature was 1.2°C to 5.8°C (Pinto *et al.*, 2011). Recently published studies for Brazil (Assad and Pinto, 2008; Margulis *et al.*, 2011) used an agronomic model approach that evaluated how current climatic risks may be altered in the coming years based on projected temperature increases in IPCC scenarios. The key elements of the study were:

- Climate projections were derived via a regional circulation model (RCM) developed by UK's Hadley Center, called PRECIS (Providing Regional Climates for Impact Studies) that projects climate to the end of the century at 50 km × 50 km resolution (relevant to most municipality sizes).
- Nine major crops (cotton, rice, coffee, sugarcane, beans, sunflower, cassava, maize, and soybean), as well as pastures and beef cattle, altogether representing 86% of the planted area in Brazil, were assessed in terms of climate risks.
- Based on a 2007 baseline risk zone mapping in 5564 municipalities for these crops, the agricultural scenarios in Brazil were simulated for the 2010s (closest representation to the current conditions), 2020s, 2050s, and 2070s using two IPCC Scenarios: A2 (most pessimistic) and B2 (slightly more optimistic). In Scenario A2, the estimated global temperature rise is between 2°C and 5.4°C; and in B2, between 1.4°C and 3.8°C.

Future evapotranspiration indexes are calculated from the three RCMs (BRAMS, ETA, and PRECIS) and four GCMs (Moss *et al.*, 2010) by using IPCC SRES A2 scenarios based on climate (temperature) projection congruence for different regions of Brazil for the 2010s, 2020s, and 2030s. The selected GCMs included: NCCCSM (CCSM3) National Center for Atmospheric Research, USA; GIER (GISS-ER), NASA Goddard Institute for Space Studies, USA; CSMK3 (CSIRO Mk 3.0), Commonwealth Scientific and Industrial Research Organisation, Australia; and INCM3 (INM-CM3.0), Institute for Numerical Mathematics, Russia.

Results

The study revealed a significant reduction in Brazil's overall suitable area for cultivation of seven of the listed crops; sugarcane and cassava were not so severely affected (see Table 1).

The economic effects for each of the crops were calculated based on projected declines in crop area for the IPCC AR4 Scenarios A2 and B2. As the production of

Table 1. Impact of climate change on current "low risk" areas suitable for cultivation (Assad and Pinto, 2008; Margulis *et al.*, 2011).

	Variation relative to current productive area (%)					
	B2 Scenario			A2 Scenario		
Crops	2020	2050	2070	2020	2050	2070
Cotton	11	−14	−16	−11	−14	−16
Rice	−9	−13	−14	−10	−12	−14
Coffee	−7	−18	−28	−10	−17	−33
Sugarcane	171	147	143	160	139	118
Beans	−4	−10	−13	−4	−10	−13
Sunflower	−14	−17	−18	−14	−16	−18
Cassava	−3	−7	−17	−3	−13	−21
Maize	−12	−15	−17	−12	−15	−17
Soybean	−22	−30	−35	−24	−34	−41

a given crop is directly proportional to the cultivated area, the impact on the area is considered to have a direct impact on production and consequently on its value.

- The results reveal that, with the exception of sugarcane, the other eight major crops analyzed in these studies are projected to decrease production, which may be more severe in some regions, such as the northeast.
- Projected losses caused by climate change on all currently produced grains are close to US$4 billion by 2050, with the soybean sector alone accounting for almost 50% of the losses (Table 2).
- Under the pessimistic climate change scenario (A2), the best current coffee production ("low risk") areas are expected to decline by at least 30%, which could result in losses of ~US$1 billion by 2050.
- However, even under the A2 Scenario, the area suitable for sugarcane could double by 2020.

The large range and magnitude of estimated production and economic impacts (up to ~US$4 billion between 2020–2050) suggests an urgent need to improve the robustness of these estimates for:

- Planning and policy purposes to ensure robust agricultural and development targets by 2050 and beyond.
- Prioritizing climate adaptation and mitigation issues both in the national interest and in the post-Kyoto (2012) context.

The lack of data or access to long-term data that is currently not in digital form is a major constraint to (1) developing robust and accurate modeling projections and (2) calibrating and validating next-generation models. Despite the fact that the

Table 2. Percentage change in "low risk" cultivation areas in Brazil due to climate change under IPCC A2 Scenario and estimated economic loss.

Crops	Reduction of "low-risk" cultivation area (%)	Scenario A2 annual economic loss (million R$)*
Rice	−12	530
Cotton	−14	408
Coffee	−175	1, 597
Beans	−10	363
Soybean	−32	6, 308
Maize	−15	1, 511
Sugar cane	+145	0, 0
Total		10, 717

*(1 US$ = 2.2 Br$)

team had access to new data sources delivered by state institutions and the National Meteorological Institute, the quality of data did not allow for more accurate climate analyses compared to previous studies.

Global and regional climate models

Atmospheric general circulation models (AGCMs) are useful tools for representing the evolution of atmospheric processes at different time scales, ranging from weather to climate. Due to the large domain covered, the typical spatial resolutions of AGCMs are of the order of a few hundred kilometers. Therefore, AGCMs are not able to handle the large number of feedback processes occurring on subgrid scales controlled by local features such as topography, shorelines, vegetation, and lakes. These small-scale processes, as well as subgrid turbulent heat and momentum fluxes, cannot be described in detail by AGCMs. The use of regional climate models makes it possible to deal with those scales. Such models can be used for climate simulations on decadal time scales and are able to take into account subgrid scale climate feedback mechanisms. Outside the domain of the regional model, surface conditions such as sea surface temperature (SST), ocean ice, and three-dimensional atmospheric fields are generally provided by the global model. During the last decade, regional climate models with horizontal resolutions on the order of 10–20 km have become available.

The use of atmospheric or coupled atmospheric-ocean global models to investigate current and future climate has increased in the last years. However, the results obtained from those models lack regional detail due to coarse resolution. For example, at the regional scale precipitation and air temperature are influenced by topography, different land-use types, or proximity to the sea. This problem can be addressed through dynamical downscaling by using regional climate models.

The IPCC A2 scenario was chosen for the project because it describes more heterogeneity in the future with continued population growth and until 2040s the projections between Scenario A2 and B2 are very similar. Economic development is primarily region-specific, *per capita* economic growth and technological development are more fragmented and slower when compared with other scenarios (IPCC, 2007). The values of the upper limits (pessimistic) and lower limits (optimistic) temperature were selected.

Based on these methods, we found the following results for some important crops in Brazil (see Figs. 4 to 6): In all cases, there is little difference between the optimistic and pessimistic scenario in 2030. However, for all cases there is an increased risk area, where the risk of producing rice, beans, and cotton is higher than 70% in comparison with the current values of less than 20%.

Simulations Based on Process-Based Models

To examine the full range of climate change impacts on agriculture, process-based dynamic crop growth models are useful tools for assessing the biophysical effects of climate on crop growth and yield (e.g., Brisson *et al.*, 2003; Jones *et al.*, 2003; Keating *et al.*, 1999; Palosuo *et al.*, 2011). These models have been accepted as predictors of the future impacts of climate change because their algorithms rely on

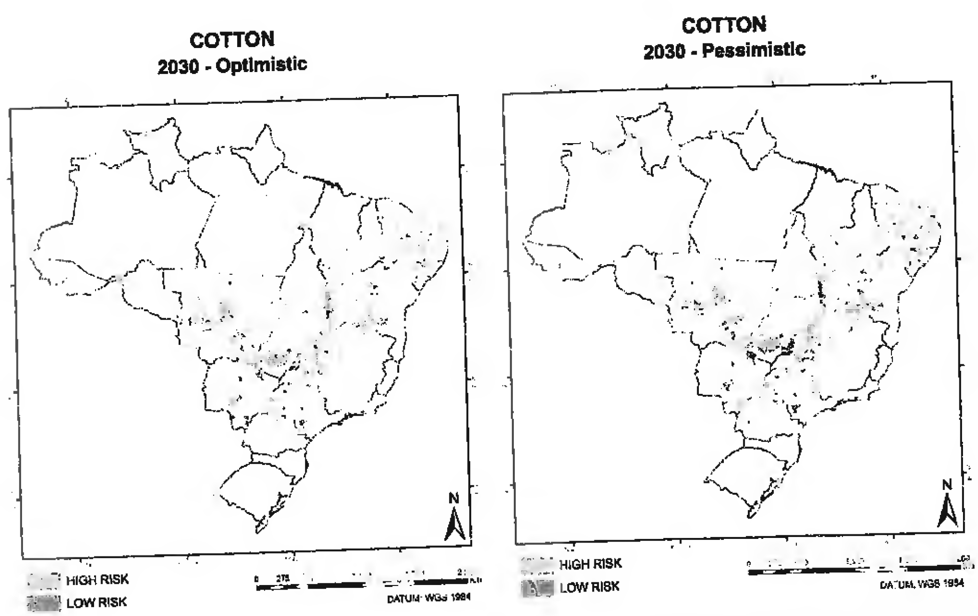

Fig. 4. Future projections for cotton simulated for two economic scenarios (Assad *et al.*, 2013, World Bank Report P118037).

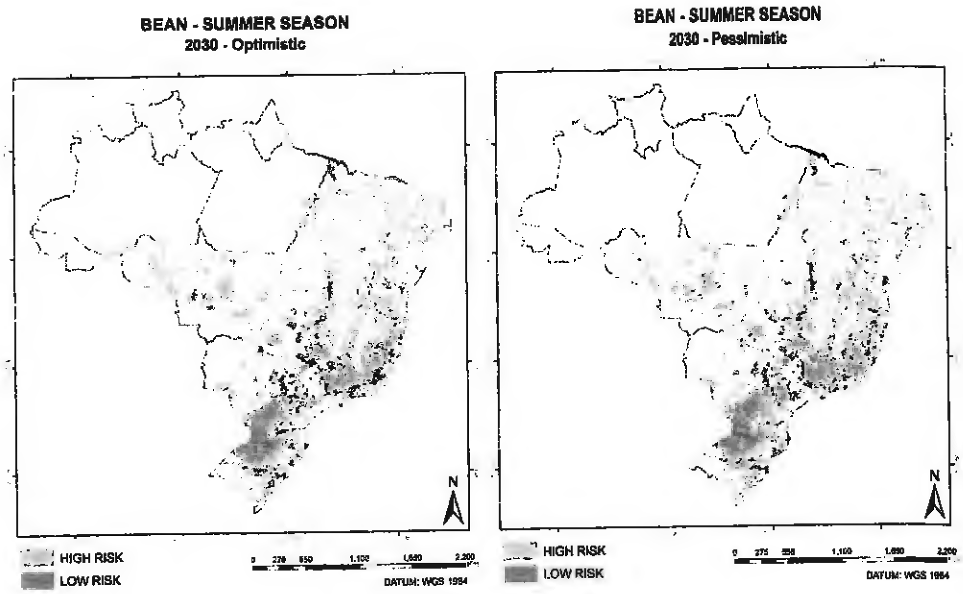

Fig. 5. Future projections for common bean crop simulated for two economic scenarios (Assad *et al.*, 2013, World Bank Report P118037).

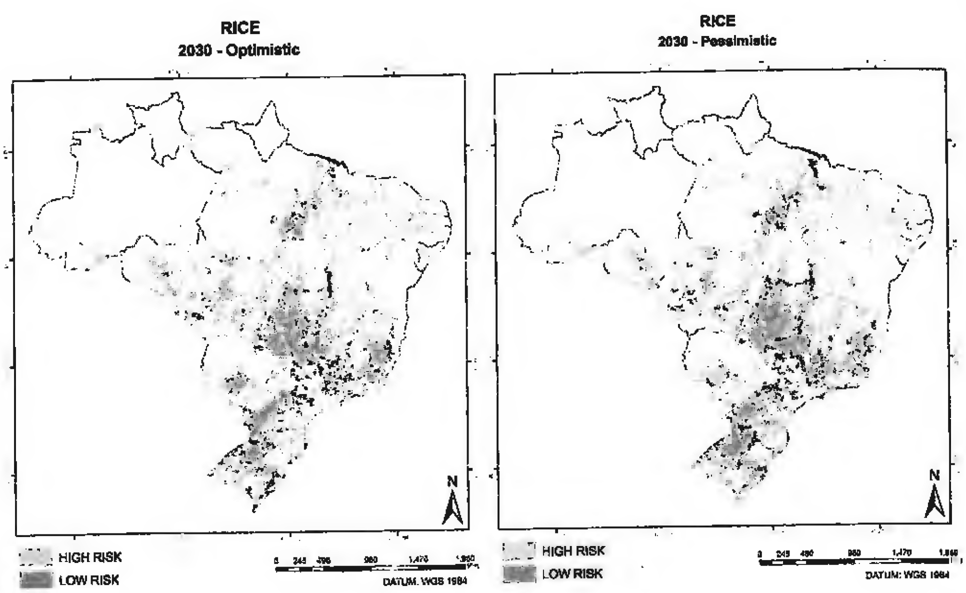

Fig. 6. Future projections for rice simulated for two economic scenarios (Assad *et al.*, 2013, World Bank Report P118037).

Table 3. P

Crops
Cotton
Rice
Sugarcane
Soybean
Rain-fed wheat
Bean (summer season)
Bean (autumn season)
Maize (summer season)
Maize (autumn season)

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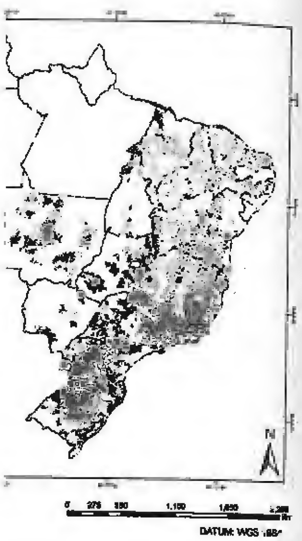

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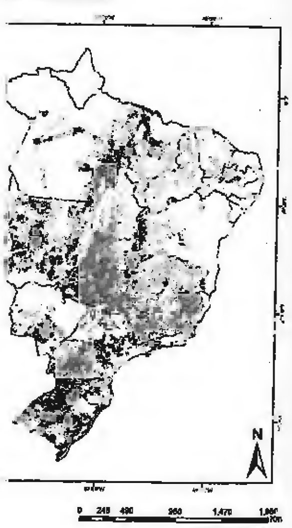

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Table 3. Percentage change in areas at low risk from climate change.

	2020		2030	
Crops	Optimistic (%)	Pessimistic (%)	Optimistic (%)	Pessimistic (%)
Cotton	−4.6	−4.8	−4.6	−4.9
Rice	−10	−7, 4	−9, 1	−9.9
Sugarcane	107	101	108	91
Soybean	−13	−24	−15	−28
Rain-fed wheat	−41	−15.3	−31, 2	−20
Bean (summer season)	−54.2	−55.5	−54.5	−57.1
Bean (autumn season)	−63.7	−68.4	−65.8	−69.7
Maize (summer season)	−12	−19	−13	−22
Maize (autumn season)	−6, 1	−13	−7, 2	−15.3

state-of-the-art physiological and physical principles for a given species (Rosenzweig *et al.*, 2013). In this section, we explore the use of process-based models for evaluating climate change impacts on agriculture, by using sugarcane as a case study. In Brazil, there are few groups able to simulate crop growth on a country scale; sugarcane is one of the crops for which this skill is already developed. This crop is chosen because it is important for mitigating climate change, given that ethanol and biomass for energy are produced from it (Goldemberg, 2007). In addition nearly 75% of the world's sugar production comes from sugarcane and Brazil is the world's biggest sugarcane producer.

To simulate sugarcane growth under several future climate scenarios, we used the DSSAT/CANEGRO model (Inman-Bamber, 1991; Singels *et al.*, 2008), as it was shown to predict successfully Brazilian sugarcane in southern Brazil (Marin *et al.*, 2011). It simulates sugarcane growth in response to climate and to water inputs, based on a physiological description of sugarcane growth and development processes. By using a daily time-step, DSSAT/CANEGRO simulates leaf and tiller phenology; leaf area and canopy cover; leaf, stalk, and root biomass; and stalk sucrose mass. As inputs, the model requires soil parameters that regulate the soil water balance (e.g., drained upper and lower limit of plant available water, saturated water content, and maximum effective rooting depth), daily weather data (e.g., solar radiation; maximum and minimum air temperature; and precipitation), and irrigation timing and amounts. Crop simulations were based on the cultivar RB86-7515, which was used in 28% of the sugarcane production area in Brazil in 2010 (PMGCA, 2011), and cultivar calibration was done by using field data obtained in five locations in Brazil, which represent three distinct soils and climates, and a total of eight treatments (Marin *et al.*, 2012).

The current climate dataset (baseline) contains 79 weather stations distributed over the state of São Paulo and portions of the neighboring states of Parana, Mato Grosso do Sul, and Minas Gerais. These locations were identified as having at least eight years of continuous daily weather measurements within the 15-year period (1992–2007). One of the future climate simulations utilized here was performed with the HadRM3P Regional Climate Model from the UK Met Office (PRECIS for present-day (1961–1990) and future (2010–2100) conditions (Alves and Marengo, 2010; Marengo *et al.*, 2009). To increase the range of future projections, this study also applied additional daily outputs of another global circulation model, namely CSIRO (Gordon *et al.*, 2002), for both A2 and B2 scenarios of climate change. Because the IPCC models investigated here vary in horizontal resolution (from 1.8 to 2.8°), the results presented have been interpolated to a 0.5×0.5 degree grid by applying OACRES (objective analysis using the Cressman scheme; Cressman, 1959).

None of the climate projections analyzed represented a yield loss for sugarcane in south Brazil, with gains ranging from 1% for PRECIS B2-late cycle to 54% for PRECIS A2-early cycle (Table 4). The largest gains were projected for the early cycle, followed by the medium and late cycle for all climate projections. This conforms to expectations, since areas harvested early normally produce larger

Table 4. Mean and standard deviation for stalk fresh mass (t/ha) and water-use efficiency (WUE, kg/[stalk DM] m^3 [ET]) for each climate scenario and percentage change compared to the baseline

Harvest time	Model	Scenario	WUE (kg/m^3)		Stalk fresh mass (t/ha)	
Early	Baseline		4.20 ± 0.90	0%	73.1 ± 32.6	0%
	CSIRO	A2	6.01 ± 0.75	43%	91.7 ± 30.1	26%
		B2	4.84 ± 0.87	15%	79.3 ± 32.3	8%
	PRECIS	A2	6.64 ± 0.50	58%	$112. \pm 21.6$	54%
		B2	5.52 ± 0.69	32%	91.2 ± 24.2	25%
Medium	Baseline		3.98 ± 0.71	0%	66.8 ± 24.4	0%
	CSIRO	A2	5.68 ± 0.57	43%	82.4 ± 22.7	23%
		B2	4.57 ± 0.68	15%	71.8 ± 24.2	7%
	PRECIS	A2	6.31 ± 0.51	58%	99.5 ± 19.8	49%
		B2	5.24 ± 0.62	32%	81.5 ± 22.1	22%
Late	Baseline		4.40 ± 0.64	0%	70.3 ± 20.5	0%
	CSIRO	A2	6.12 ± 0.55	39%	84.7 ± 17.4	20%
		B2	5.01 ± 0.60	14%	75.4 ± 20.2	7%
	PRECIS	A2	6.23 ± 0.59	41%	86.9 ± 17.9	24%
		B2	5.10 ± 0.66	16%	71.2 ± 18.8	1%
Weighted average				34%		22%

amounts than areas harvested later. For the most commonly used cultivar in south Brazil, sucrose concentration follows a distinct trend, as medium cycle crops show higher sucrose concentration than early and late cycles. Therefore, we would expect increases in sucrose production mainly for the medium cycles given the rise in the stalk yield and the maintenance of high sucrose concentration in such fields. Knox *et al.* (2010) simulated climate change impacts for irrigated sugarcane production in Swaziland, and found similar trends for sucrose content and stalk fresh mass (SFM) for PRECIS downscaled projections for the 2050s, with a decreasing trend for future projections for both sucrose production and SFM, unless irrigation were included in the simulations.

Weighted averages for simulated (SFM) were 22% higher than the baseline (Table 4). Simulations using CSIRO climate projections resulted in an average increase of 15% compared to the baseline, while PRECIS climate projections resulted in a 29% increase. Interestingly, CSIRO projected rainfall increase by about 62% to 79%, mainly during the dry period of the year, with very small changes in temperatures for the A2 and B2 scenarios. PRECIS, on the other hand, projected an increase in temperature around 2°C for both economic scenarios, and decrease in rainfall by 25% to 30%. CSIRO projections also include a slight decrease in solar radiation while PRECIS scenarios had increased solar radiation, on average. These climate projection differences are distinctly reflected in sugarcane yields, because the routes to the outcomes were different for each of the climate projections used. For the CSIRO model, the yield increases occurred mostly because of projected higher rainfall. The PRECIS model, in turn, produced higher yields because of the positive effects of higher temperature during periods with adequate soil water supply, in addition to the elevated CO_2 concentrations.

Given the range of the results analyzed here, we can conclude that the benefit of increased temperature and elevated CO_2 concentration may override the disadvantage of reduced rainfall (as projected by PRECIS) for sugarcane crops in south Brazil. However, sugarcane may also be limited by solar radiation, not only by rainfall (Vu and Allen, 2009).

Besides the increase in average yield, future climate projections also present a decrease in the SFM temporal variability for the three harvest dates, which would correspond to a reduction in the production risks for sugarcane, mainly for the PRECIS projections in the early and medium cycles. The lower probability of low yields in future climates represents a major favorable impact for Brazil as a whole and needs to be further investigated. Recently, oscillations in sugarcane yields due to weather and management have had social and economic repercussions, with several sugar mills closing doors, which has resulted in thousands of unemployed workers.

Maps of SFM variation (Fig. 7) show the major SFM increases for the central-north region of the state of São Paulo, which has soils with high water-holding

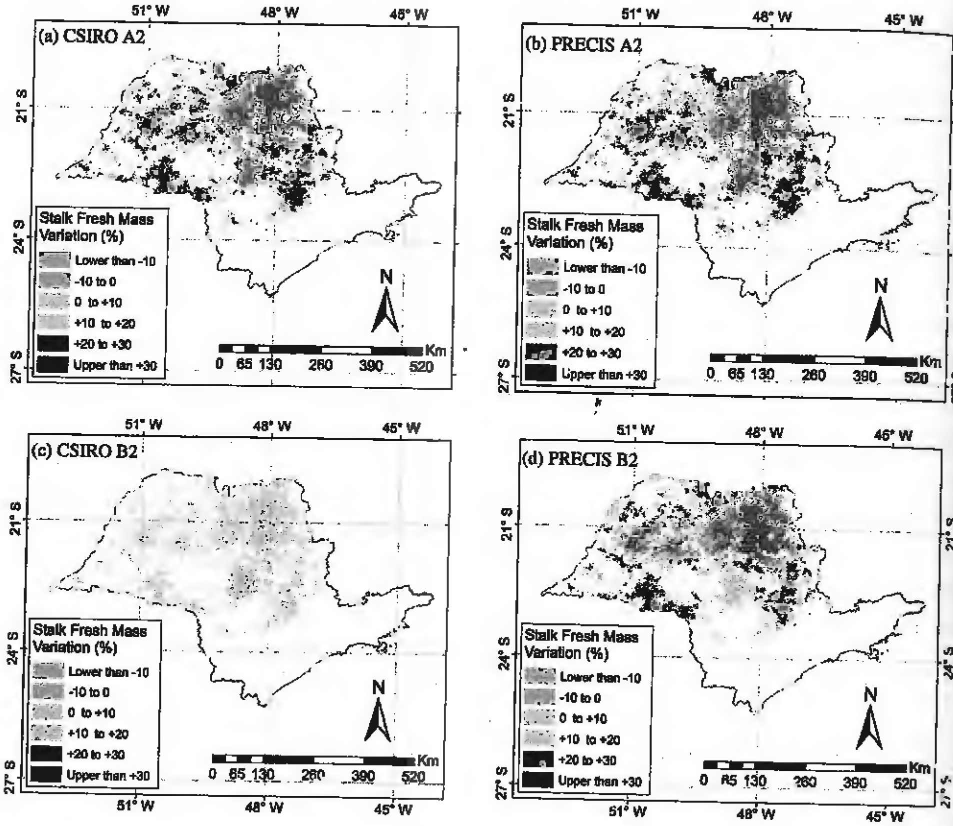
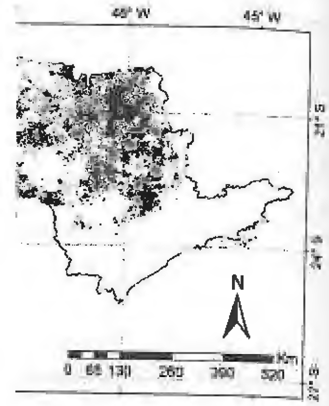
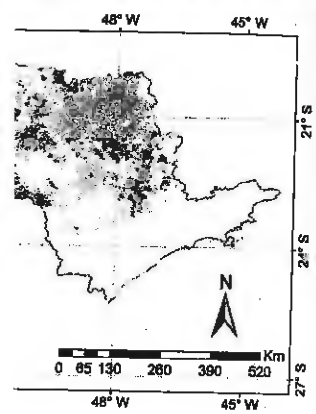


Fig. 7. Spatial distribution of the difference in SFM simulated for the baseline growing area of sugarcane within the state of São Paulo in 2011 and for future projections based on downscaled A2 and B2 scenarios from CSIRO and PRECIS.

capacity, adequate temperatures, and high amounts of rainfall and solar radiation. Results show that the area that is currently being used for sugarcane in São Paulo is projected to experience higher yield gains than those predicted to occur for the entire state of São Paulo. This may be related to climate conditions in the central and northern parts of the state where the climate is hotter and drier than the southern part, where sugarcane has not been cultivated (Fig. 7). Under an increased temperature scenario, south São Paulo state may become more suitable for sugarcane production in the future, since currently the cold period limits sugarcane growth and yield. On the other hand, it is reasonable to argue that the western and northwestern part of the state would be favorably affected by climate change (Fig. 7), due to current water and temperature stresses on sugarcane, which should enhance the effect of CO_2 fertilization on photosynthesis and yield (Marin *et al.*, 2011).





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AgMIP South America

With the current strengthening of policy research on climate change and agriculture in Brazil, EMBRAPA is partnering with AgMIP for the AgMIP South America project. The project was established to use advanced approaches for assessing impacts of climate change and variability on agriculture in Brazil and to evaluate adaptation options that will lead to more resilient agricultural systems, increased food security, and reduced poverty in Brazil. Through this partnership, AgMIP and EMBRAPA will cooperate in research for advancing agricultural models and scientific capabilities for integrated assessments of climate change impacts and adaptation, as well as collaborate in activities that lead to improved agricultural models, data, methods, and assessments.

Conclusion

The framework of the AgMIP protocols complements the modeling of crops in Brazil. The evolution of this research base now allows the possibility to compare at least three crop models; DSSAT, APSIM, and STICS (Simulateur multidisciplinaire pour les cultures standards, Brisson *et al.*, 2003). The Brazilian researchers participating in AgMIP created the AgMIP-BR project to provide advances in comparing model results in locations across the world. Since 2014, the Brazil AgMIP team has participated in the development of the AgMIP ATLAS Project (Agro-Economic Dynamics and Trade-offs of Land Use and Sustainability). The AgMIP ATLAS project will undertake the research needed to understand the system dynamics, map emerging hot-spots of food-security and environmental degradation, identify global-change test-beds for targeted interventions, and conduct improved scenario-based multi-model assessments of adaptation strategies and tradeoffs on the global scale and in specific focal regions. The resulting atlas of consistent multi-scale information products will guide decision-makers in a challenging and interconnected future.

Another important result is the cooperation agreement between EMBRAPA and the USDA for effective collaboration in the AgMIP program.

The possibility of using the AgMIP protocols for regional integrated assessments is already helping to identify areas of high climatic risk in Brazil for the next 20 years and to estimate the productivity of the main Brazilian crops. Advanced studies of extreme events show the need for Brazil to quickly search for adaptation options for agriculture, which plays a significant role in the national economy. Taken together, these activities have great potential to contribute to science-based public policies linked to climate change in the country.

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